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Journal of Materials Processing Technology 189 (2007) 1–12

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Review

Soft magnetic composite materials (SMCs)

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Received 4 July 2006; received in revised form 1 January 2007; accepted 20 February 2007

Abstract

Soft magnetic composites (SMCs), which are used in electromagnetic applications, can be described as ferromagnetic powder particles surrounded by an electrical insulating film. SMC components are normally manufactured by conventional PM compaction combined with new techniques, such as two step compaction, warm compaction, multi-step and magnetic annealing followed by a heat treatment at relatively low temperature. These composite materials offer several advantages over traditional laminated steel cores in most applications. The unique properties include three-dimensional (3D) isotropic ferromagnetic behavior, very low eddy current loss, relatively low total core loss at medium and high frequencies, possibilities for improved thermal characteristics, flexible machine design and assembly and a prospect for greatly reduced weight and production costs. With expanded applications of soft magnetic composite materials expected in the future, a review of the magnetic properties, characteristics, processing and applications of SMCs is presented in this article.
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Keywords: Soft magnetic composites; Core loss; Magnetic properties; Organic coating; Inorganic coating

Contents

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0924-0136/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.jmatprotec.2007.02.034

1. Literature review

Magnetic materials have revolutionized our lives. These materials are used in electronic, computer and telecommunication industries. During the last decades different types of magnetic materials have been used including pure iron and its alloys, such as Fe–Ni, Fe–Ni–P, Fe–Nd–B and Fe–Si and soft and hard ferrites, such as Ni–Zn, Mn–Zn and Ba ferrites. Different aspects of processing, properties, effect of additives on magnetic properties and applications of these ferrites were discussed by many researchers [1–50] including these authors who studied the effects of additives, such as V_2O_5 and MoO_3 in Mn–Zn–ferrites for low consumption lamps and high frequency applications [39,40]. New materials including amorphous materials, amorphous wires, nanocrystalline materials and today's soft magnetic composite materials are the latest development in magnetic history [46–83]. It is worth reviewing the highlight of the magnetic materials development very briefly, before going to more details about SMCs.

The idea of using iron–resin composites for soft magnetic applications is not new. It appeared more than 100 years ago but iron–resin composites have been rarely used because their properties, the processing technology for making parts and real needs for these materials were not sufficiently developed. However, these limitations were being overcome with the development of improved raw materials and new shaping technologies. These composites find increasing use in electrical motors, replacing existing laminate materials [53,56,59,65,68–73]. These materials are being developed to provide materials with competitive magnetic properties (good relative permeability and magnetic saturation), but with high electrical resistivity [49]. Insulated iron powder (Fig. 1) offers several advantages over traditional steel in some applications, for example, the isotropic nature of the SMC combined with the unique shaping possibilities opens up for 3D-design solutions [55,56]. In recent years, effects of particle size, particle composition (Fe–Ni, Fe–Ni–Co, Fe–Si) [1–8], compaction parameters (warm compaction, pressure, lubricant), resin and wet chemical methods for creation of insulation layer around particles have been verified [2,6,7,53,60]. A literature survey in the field of soft magnetic composite materials is given in Table 1, where a summary of some recent developments is presented.

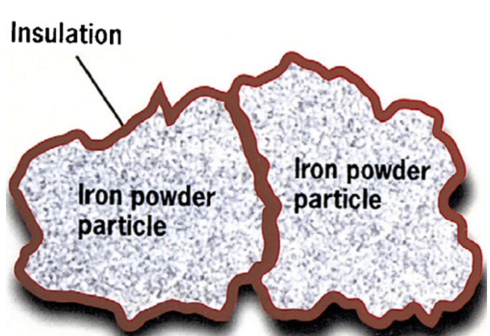

Fig. 1. A schematic diagram of the component elements of a powder core [65].

2. Introduction

During the last several years, interest in the study of soft magnetic composites (SMCs) has been increasing at an accelerating rate, stimulated by recent advances in materials synthesis and characterization techniques and the realization that these materials exhibit many unique and interesting physical and chemical properties with a number of potential technological applications. They play a key role in power distribution, make possible the conversion between electrical and mechanical energy, underlie microwave communication, and provide both the transducers and the active storage material for data storage in information systems.

New developments in powder composites make SMC materials interesting for applications in electrical machines, when combined with new machine design rules and new production techniques. These composites have several advantages, such as reduction in weight and size. Weight can be reduced through several types of technology improvements; in materials, design techniques and fabrication processes. To establish the design rules, one must pay attention to electromagnetic loss characteristics of SMC materials. Several different series of iron-based SMCs are: (1) pure iron powder with resin, (2) sintered iron-based powders, (3) pure iron powder with additions of Zn-stearate and carbon, (4) iron-based powder alloys (Fe, Ni, Co, Si), (5) commercially available iron powder "Somaloy" [70–75]. Among these, the composite materials minimize fringing flux due to their distributed air gap.

An interesting example of recent commercial progress for SMC applications is the BDC-motor, shown in Fig. 2 for ABS type brake systems produced by Asian Seiki Co. Ltd., Japan [65]. The SMC machine must be designed using short magnetic path length and minimum weight. In some applications, such as magnetic cores and magnetic machines, these composites are able to replace electrical steel sheets or ferrites [63].

3. Magnetic characteristics and properties

Two key characteristics of an iron core component are its magnetic permeability and core loss characteristics. The magnetical, electrical and mechanical characteristics depend on the preparation and processing of the components. In addition the materials purity, shape and size of particles influence the overall magnetic response.

Two basic types of soft magnetic materials are extensively used, depending on the application and its requirements. These materials are:

(a) Ferrimagnetic materials, which are based on ceramic oxides of some metals, such as ferrites and are applicable to frequencies from a few kilohertz to well over 80 MHz.
(b) Ferromagnetic materials based on iron and nickel, which are for lower frequency applications, <2 kHz, consist of iron-based alloys which have low to medium frequency applications in electric machines. SMCs are ferromagnetic materials with significantly improved medium to high frequency properties which made them a viable alternative to

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